Production, persistence and diversity of species in temperate grasslands

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ABSTRACT

Temperate grassland areas are considered to be semi-arid, with rainfall typically between 250 and 500 mm, much of it occurring in the late spring and early summer. Grazing plays an important role in all these grasslands with impacts on diversity and persistence. Against this assumption that seasonal productivity would be more uniform within a pasture that was diverse, the research suggested that species rich pastures were less stable, because this species richness was composed of non-perennial, volunteer and weed species. This paper explores the concept that systems diversity of temperate grassland does not always equate to production. In these systems the functional role of perennial grasses is important both for the productive capacity and protection of soil through the maintenance of cover, hence represents the key element which needs to be preserved through management strategies.

Key words : Management, Native species, Pasture, Perennial, Prairie, System

Introduction

Temperate grasslands are located north of the Tropic of Cancer (23.5°N) and south of the Tropic of Capricorn (23.5°S)(Fig. 1). The major temperate grasslands include the veldts of Africa, the pampas of South America, the steppes of Eurasia, the prairies of North America and the grasslands of south-eastern Australia.

Temperate grassland areas are considered to be semi-arid, with rainfall typically between 250 and 500 mm, much of it occurring in the late spring and early summer (Fig. 2). In some of these temperate areas, this falls as snow, serving as a reservoir of moisture for the beginning of the growing season. Temperate grasslands have hot summers and cold winters. Summer temperatures can be well over 40°C, while winter temperatures can be as low as -20°C. Seasonal drought and occasional fires help maintain the dominance of grass over woody perennials in these areas.

The lack of trees and the high natural fertility of these areas make their conversion to extensive agricultural animal production relatively easy. As a result, a key feature worldwide of most of the grazing lands in these areas is that they have undergone significant disturbance since colonisation. These disturbances (e.g. uneven grazing, fertilisation, sub-division) coupled with the invasion of introduced species means that few of the original communities remain, particularly on farms. These grasslands therefore can be a mixture of either sown, invasive volunteers or natives, dependant on local climate, management and soil conditions.

Grasses and forage species contribute substantial value via pasture production for dairy, beef, wool, lamb and other products. In Australia, commodities that result from pasture production have been valued at $9.3 billion (ABARES, 2011). Within the temperate grassland region of Australia these pasture systems are considered to have additional

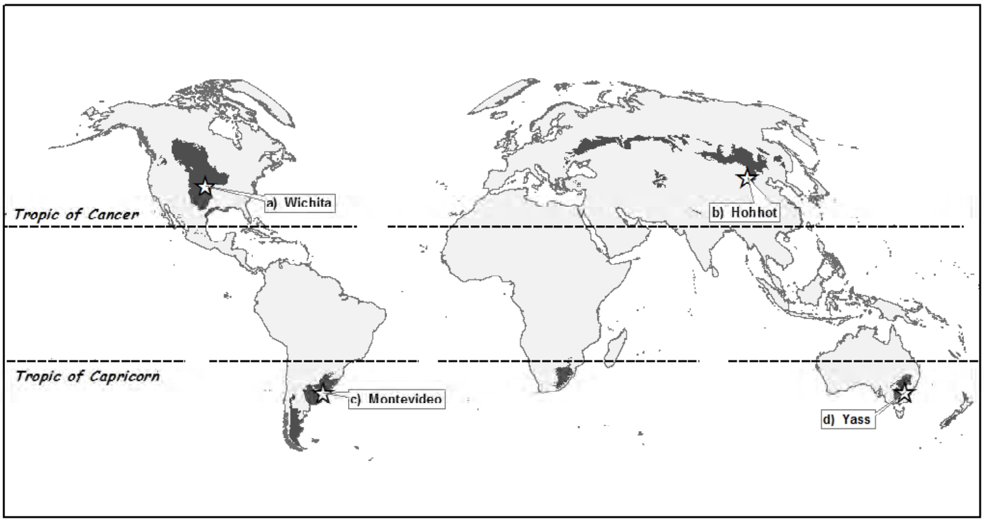

Fig. 1. Location of worldwide temperate grasslands, the veldts of Africa, the pampas of South America, the steppes of Eurasia, the prairies of North America and the grasslands of Australia.Climate station locations presented in Fig. 2 a) Wichita, Kansas, USA; b) Hohhot, China; c) Montevideo, Uruguay and d) Yass, NSW, Australia.

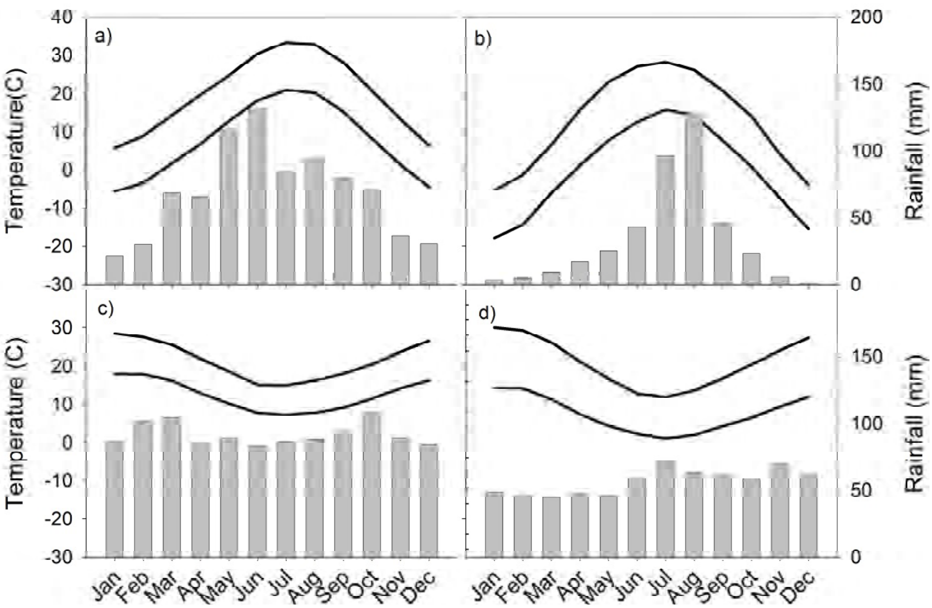

Fig. 2. Monthly rainfall (mm) (grey bars), minimum and maximum monthly temperature (°C) for selected temperate grassland areas, a) Tallgrass Prairie, Wichita, Kansas, USA (37.6889° N, 97.3361° W); b) Steppe, Hohhot, China (40.8167° N, 111.6500° E); c) Pampas, Montevideo, Uruguay (34.8836° S, 56.1819° W); d) South-eastern Australia, Yass, NSW, Australia (34°40'S, 148°54'E). Data from http://worldweather.wmo.int/en/home.html

value over their production potential, contributing a 'difficult-to-measure' value in providing ecosystem services. These services include increased water use, thus, correcting hydrological imbalances associated with annual cropping systems (Farrington *et al.* 1992; Barrett-Lennard 2002), improving soil stability (Le Houérou 1992), habitat for native animals (Lancaster *et al.* 2012) and amenity species in facilities such as sports grounds and golf courses as well as in residential gardens (Chapman *et al.* 2012).

The productivity of a grassland system can be measured in terms of outputs in relation to inputs and is often increased through higher carrying capacity (stocking rates) and thus more production per hectare (Graham *et al.* 2003). Within these grassland systems, persistence of desirable species under variable climate and management regimes is a key measure of the health of a system. This paper explores the relationships between production, persistence and diversity within temperate grasslands, with consideration of how the environment and specific management influence and alter these systems.

Production

In practice most grasslands that are used for livestock production include mixtures of four groups of plants, viz. perennial grasses, annual grasses, legume and other broadleaf species (herbaceous and woody) (Kemp *et al.* 2000). These mixtures exist, irrespective of whether the pasture is sown or naturalised (Kemp *et al.* 2000). The challenge that producers have is to select and apply management tactics that will optimise these mixtures to maintain production, minimise weed invasions, and minimise adverse effects on soil chemistry, the water table and salinity (Kemp *et al.* 2000).

Within grasslands, the variability in herbage production from year-to-year is largely induced by variability of precipitation (Owensby and Auen 2013). The stocking rate of these grasslands therefore is also highly variable, depending on season.

Grazing implicitly results in variation in the frequency and intensity that plants are defoliated over time with consequent variable impacts on the persistence and productivity of those species (Kemp *et al.* 2000). By regulating grazing patterns, grazing management is a key tool in controlling persistence of desirable species within the pasture system(Kemp *et al.* 2000). Grazing management is important, as continuous grazing can result in the reduction of the total perennial grass component over time (Avery *et al.* 2000; Graham *et al.* 2000; Lodge and Orchard 2000; Virgona *et al.* 2000) or as a relative change in species composition (Garden *et al.* 2000).In Australia, a stable perennial grass pasture cannot be maintained under continuous grazing in the high rainfall zone, even when grazing pressure is moderate (Kemp *et al.* 2000).

Persistence

Persistence of pastures is very important as resowing rates in areas of southern Australia are less than 1% per year (Kemp and Dowling 2000). When productive pastures are established they need to be maintained. The profitability of sowing new pastures is marginal when prices for livestock products are low (Vere *et al.* 2001).Pasture resowing in Australia occurs on average only once every 20 years in one of the most favourable areas for sown pastures(Malcolm *et al.* 2014). However within temperate grasslands, most areas have never been sown and are still dominated by native grass species.

To ensure species persistence, control of grazing is essential. In many instances the performance of perennial grasses within pastures is based entirely on the performance of existing plants, as recruitment of perennial grasses is a rare event (Briske, 1996; Kemp *et al.* 2000).Seedling recruitment within established pastures is frequently low, only occurring sporadically during years with favourable moisture and temperature conditions, or when disturbances create spaces (Lodge and Whalley 1981; Briske 1996; Virgona and Mitchell 2011; Mitchell *et al.* 2014).The seedbanks of pastures in temperate areas tend to be dominated by annual species, with very few perennial grasses present (Mitchell *et al.* 2014). There is limited published information on the survival of new recruits to form adult plants. This highlights the importance of maintaining existing perennial plants in a vigorous state.

Diversity

When we are considering diversity within these temperate grassland systems we need not just to consider the overall diversity or even the plant diversity, but the functional diversity is a key factor also(Virgona 2006). For example, short term productivity can be increased with increased phosphorus (P) supply with no impact on plant diversity numbers, but in most instances this reduces the functional diversity through increasing the dominance of undesirable annual grass and broadleaf species and therefore impairs productive landscape function (Virgona 2006).

In their original state many of the temperate grasslands were dominated by a mixture of C3 and C4 species (Table 1). Grazing induced changes mainly consisted of the tall

Table 1. Examples of four different temperate grassland types, in terms of location, major species, enterprise and production.

Grassland	Location	Main native species present	C_3/C_4	Enterprise	Production (mean annual herbage mass kg DM/ha)
Pampas of Southern South America[1]	San José, Uruguay 34°19′S, 57°02′W	*Paspalum notatum* *Stenotaphrumsecundatum*, *Cynodondactylon* *Stipaneesiana* *Stipapapposa*	C_3 and C_4	cattle	7,770
Mongolian-Manchurian grassland[2]	Xilinhot, China 43°43′N, 116°38′E	*Leymuschinese* *Stipagrandis* *Agropyroncristatum* *Caraganamicrophylla* *Poaargunensis*	C_3	wool/sheep /goats	2,487
Flint Hills tall grass prairie[3]	Manhattan, Kansas 39°12′N, 96°35′W	*Andropogongerardii* *Sorghastrumnutans* *Andropogonscoparius* *Poapratensis*	C_3 and C_4	cattle	4,250
Grasslands of South-eastern Australia[4]	Yass, NSW 34°40′S, 148°54′E	*Rytidosperma*spp. *Microlaena stipoides*	C_3	wool/sheep	2,585

[1]Altesor *et al.* (2005); [2]Xiangming *et al.* (1996) and Ni (2004); [3]Owensby and Auen (2013) and Owensby *et al.* (2008); [4]Garden *et al.* (2003)

C4 species being replaced by the shorter C3 species. The native grasslands of south eastern Australia were dominated originally by tall C4 grass, e.g. *Themedatriandra* (Lodge and Whalley 1989; Lunt *et al.* 2007). The shorter C3 grasses, e.g. *Rytidosperma* spp., now dominates these grasslands. This change in functional group dominance has also been observed in the grasslands of South America (Altesor *et al.* 2005). For animal production purposes, C3 species are more desirable than C4. In general, C4 grasses have a higher fibre and lower protein content of their leaves and consequently a lower digestibility than that of C3 grasses (Lodge and Whalley 1983; Archer and Robinson 1988).

Surveys of native grasslands indicate that diversity of native species decline under heavy grazing and/or fertiliser use (eg. Reseigh *et al.* 2003; Dorrough *et al.* 2006). In general strategies that lead to increases in productivity, lead to declines in plant diversity and this is particularly the case in situations where large applications of P fertiliser have been made (Dorrough *et al.* 2006).

In a spatially variable landscape, diversity also exists within a grassland. This 'within paddock' variation is created by changes in aspect, slope, soil water holding capacity and soils. In grasslands in southern Australia, higher quality species such as *Microlaena stipoides* and *Trifolium subterraneum* were more prevalent on the lower slopes, which have deeper soils and a higher production potential, while the rocky upper slopes were dominated by *Rytidsperma* spp. and had a much lower production potential (Badgery *et al.* 2013). These differences were related to soil water holding capacity. The low production zone had annual pasture growth of 4.6 t DM/ha/yr, and a plant available water of 45 mm, whereas the high production zone, occupying the lower slopes, produced 9.9 t DM/ha/yr and a plant available water of 65 mm (Badgery *et al.* 2013).

Diversity, persistence and production

A major pasture project within southern Australia explored the relationship between plant diversity, persistence and productivity, within the context of grazed pasture systems(Kemp *et al.* 2003). In principle, plant biodiversity may be positively or negatively related to productivity and pasture persistence, depending on the productive capacity of the ecosystem, the characteristics of individual species and the functional diversity of the species present (Grime 1973; Tillman 1982).Many sown pastures initially only contain a few sown species (typically 2 or 3), other species (volunteers and weeds) usually invade to occupy available niches (Kemp *et al.* 2003),whereas native pastures can contain a substantial number of species.Kemp *et al.* (2003) found no universal relationship between plant species diversity and pasture productivity in an experiment of ten field sites across southern Australia. However, the sites with the highest plant species diversity had the lowest productivity. Productivity was maximised when 10-20 species were present in the pastures (Kemp *et al.* 2003).

It would be expected that seasonal productivity would be more uniform within a pasture that was diverse, with all possible niches fully exploited, enabling the full growth potential of the whole pasture to be realised (Kemp *et al.* 2003). However, the results suggested that species rich pastures were less stable, as much of this species richness was composed of non-perennial, volunteer and weed species.

The Prairies of North America

The prairies form a triangular area from Alberta, Saskatchewan, and Manitoba down through the Great Plains to southern Texas and Mexico(Fig. 1).The prairies of North America are a combination of both warm and cool season species, with tall, mid and short grass prairies, their distribution dependent on rainfall. Most the original prairies have been modified and are set stocked with cattle. Grass provides the cheapest means of weight gain for cattle.

For nearly 40 years The Land Institute, Kansas, has conducted research on natural systems agriculture using the prairies as the basis for sustainable agriculture with the aim of producing ecologically sound perennial food-grain-producing systems(Jackson 2002). Natural systems are highly efficient in nutrient recycling, use of solar energy, and biodiversity preservation, but they cannot support food requirements of human populations. The prairie system is composed of four functional groups – warm and cool season grasses, legume and composite (sunflower) family members. These functional groups complement one another in resource use, both spatially and temporally. The ultimate aim is for agriculture to shift from annual monocultures to systems that are diverse, with perennial vegetation that is capable of producing edible grain in abundance. The Land Institute conducts a breeding program that is focused on perennialising wheat, sunflower and sorghum(Van Tassel and DeHaan 2013).

Differences in seed yield between annual and perennial species have been cited to support the theory that there is a strict trade-off between grain yield and perenniality. The theory is based on comparisons between groups of existing species, but does not account for progress that can be achieved genetically and physiologically through human-directed selection. The fundamental assumption that the pool of carbon shared by reproductive and vegetative structures is fixed and cannot be increased by breeding is contentious. According to Cox *et al.* (2010) there need not be a gram-for-gram trade-off between grain production and perennial structures.

The re-establishment costs for an annual crop species include the energy embodied in the seed that is sown, the energy to prepare the paddock, and the energy invested in early growth and establishment. By one calculation, the energy costs of sowing and establishing a hectare of annual wheat is equivalent to the energy contained in 715 kg of wheat grain, amounting to 32% of the crop's yield (Cox *et al.*, 2002).

Grassland of temperate Australia

About 3.1 million hectares (22%) of the agricultural area of south-eastern Australia can be classified as native pasture (Hill *et al.*, 1999), and is generally located in the high rainfall zone (> 600 mm annual average rainfall) of the southern agricultural zone (Fig. 2). Much of this area has soils that are shallow, low in P, acidic (pH_{CaCl2}< 5.5) and are considered non-arable (Simpson and Langford 1996); therefore are unsuitable for the sowing of introduced species.

A survey of native pastures was undertaken in the autumn of 2004 in the Lachlan, Murrumbidgee and Murray catchments of south eastern Australia (Virgona and Mitchell 2011). A total of 59 farms located between the 550 700 mm rainfall isohyets were randomly chosen and farmers asked to nominate paddocks that had not, or were not, going to be sown to introduced perennial species. One of these paddocks was chosen at random on each farm and surveyed. The survey was conducted in early autumn – at a time when winter growing annual species would normally be under represented.

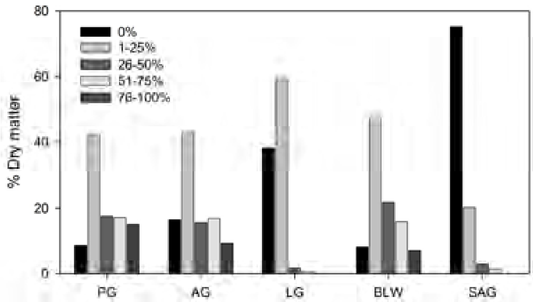

Fig. 3. The percentage of site within each of the percentage dry matter composition frequency classes, where PG is perennial grass, AG is annual grass, LG is legume, BLW is broadleaf week, SAG is summer annual grass.

The results showed that native perennial species were common in these paddocks, although they were rarely dominant (Fig. 3).The most frequently found native species were *Bothriochloamacra* and *Rytidosperma* spp.(Virgona and Mitchell 2011). Potential production was determined through modelling the daily growth at each site location, incorporating the measured pasture composition, fertility and climate over 50 years at each site. The modelling incorporated the seasonal growth and digestibility of each pasture species to determine potential productivity of grazing wethers. In these grasslands, surveyed carrying capacities increased with increases in the number of perennial species in the system (Fig. 4).However, the same relationship was not true for diversity and carrying capacity (Fig. 4). There are probably several reasons for this. These systems are highly modified with lots of volunteer and weed species. The time of year of the survey, completed during the summer months, may not have recognised all species that existed in the grasslands. There is a strong inverse relationship between the amount of broadleaf weed present in the system and the carrying capacity.

The productivities of these grasslands are low, however they are in line with other published data. In temperate Australia, year-round stocking rates of about 0.5–2 dry sheep equivalents (DSE) per ha(or the equivalent in cattle) are carried on non-degraded native pastures(Wolfe 2009). Considering the scarcity of perennials in the grasslands, any management options that favoured native perennial grass would be advantageous(Virgona *et al.* 2003). The recruitment of new individuals is a rare event, however grazing management can have an impact on basal cover. While reinvasion of

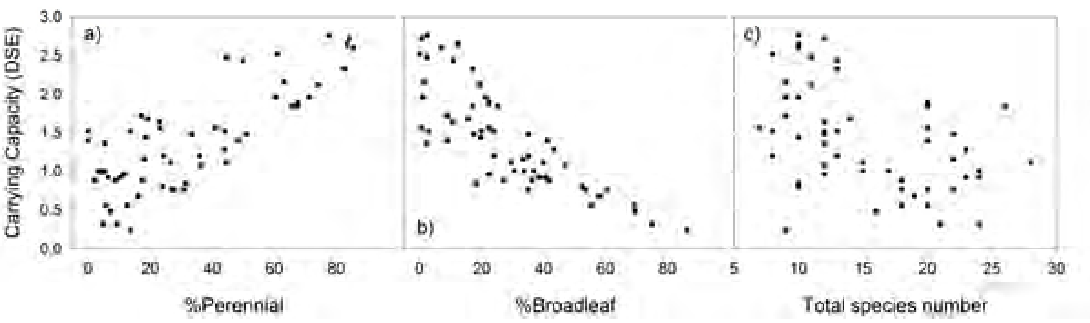

Fig. 4. The carrying capacity, expressed as DSE (dry sheep equivalent), plotted against the a)percentage perennial grasses, b) percentage broadleaf weeds and c) total number of species for the 59 farms surveyed.

pastures by native species has been reported (eg. Garden *et al.* 2001), developing management strategies to encourage the process has been elusive. It is likely that recruitment events are episodic and therefore reliant on the right combination of season and management.

Conclusions

The temperate grasslands of the world cover large areas and are valuable for many grazing enterprises. Grazing plays an important role in all these grasslands with impacts on diversity and persistence. The persistence of existing plants is important as recruitment in these grasslands is a rare event. When strategic grazing management options require significant rest periods (eg. Nie and Zollinger 2011), there are implications in terms of greater productivity from other pastures available on farm in order to maintain profitability. The implications for these other pastures also need to be taken into account when applying strategic grazing management.

In these systems diversity does not always equate to production, as these grasslands are highly modified. It is more important to consider functional diversity, rather than total species diversity. In these systems the functional role of perennial grasses is important both for the productive capacity and protection of soil through the maintenance of cover, hence they represent the key element which needs to be preserved through management strategies.

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References

ABARES (2011). 'Agricultural commodity statistics 2011.' Canberra)

Altesor, A., M. Oesterheld, E. Leoni, F. Lezama and C. Rodríguez. 2005. Effect of grazing on community structure and productivity of a Uruguayan grassland. *Plant Ecology* 179: 83-91.

Archer, K. A. and G. G. Robinson. 1988. Agronomic potential of native grass species on the Northern Tablelands of New South Wales. II. Nutritive value. *Australian Journal of Agricultural Research* 39: 425-436.

Avery, A. L., D. L. Michalk, R. P. Thompson, P. Ball, T. Prance, C. A. Harris, D. W. FitzGerald, J. F. Ayres and B. A. Orchard. 2000. Effects of sheep grazing management on cocksfoot herbage mass and persistence in temperate environments. *Australian Journal of Experimental Agriculture* 40: 185-206.

Badgery, W., M. Mitchell, F. Cox, G. Millar, P. Cranney, L. McCormick and K. Sargeant. 2013. 'Landscape variability can be identified, mapped and managed.' Available at http://www.evergraze.com.au/library-content/managing-native-pastures-by-identifying-and-mapping-production-zones/ [Accessed 23 September 2014].

Barrett-Lennard, E. G. 2002. Restoration of saline land through revegetation. *Agricultural Water Management* 53: 213-226.

Briske, D. D. 1996. Strategies of plant survival in grazed systems: a functional interpretation. In 'The ecology and management of grazing systems.' (Eds J Hodgson, A Illius.) pp. 37-67. (CAB International: UK)

Chapman, S. C., S. Chakraborty, M. F. Dreccer and S. M. Howden. 2012. Plant adaptation to climate change - opportunities and priorities in breeding. *Crop and Pasture Science* 63: 251-268.

Cox, T. S., M. Bender, C. Picone, D. L. V. Tassel, J. B. Holland, E. C. Brummer, B. E. Zoeller, A. H. Paterson and W. Jackson. 2002. Breeding Perennial Grain Crops. *Critical Reviews in Plant Sciences* 21: 59-91.

Cox, T. S., D. L. Van Tassel, C. M. Cox and L. R. DeHaan. 2010. Progress in breeding perennial grains. *Crop and Pasture Science* 61: 513-521.

Dorrough, J., C. Moxham, V. Turner and G. Sutter. 2006. Soil phosphorus and tree cover modify the effects of livestock grazing on plant species richness in Australian grassy woodland. *Biological Conservation* 130: 394-405.

Farrington, P., R. B. Salama, G. D. Watson and G. A. Bartle. 1992. Water use of agricultural and native plants in a Western Australian wheat belt catchment. *Agricultural Water Management* 22: 357-367.

Garden, D. L., P. M. Dowling, D. A. Eddy and H. I. Nicol. 2001. The influence of climate, soil, and management on the composition of native grass pastures on the central, southern, and Monaro tablelands of New South Wales. *Australian Journal of Agricultural Research* 52: 925-936.

Garden, D. L., N. J. S. Ellis, M. A. Rab, C. M., Langford, W. H. Johnston, C. Shields, T. Murphy, M. Holmberg, K. B. Dassanayake and S. Harden. 2003. Fertiliser and grazing effects on production and botanical composition of native grasslands in south-east Australia. *Australian Journal of Experimental Agriculture* 43: 843-859.

Garden, D. L., G. M. Lodge, D. A. Friend, P. M. Dowling and B. A. Orchard. 2000. Effects of grazing management on botanical composition of native grass-based pastures in temperate south-east Australia. *Australian Journal of Experimental Agriculture* 40: 225-245.

Graham, J. F., B. R. Cullen, G. M. Lodge, M. H. Andrew, B. P. Christy, P. J. Holst, X. Wang, S. R. Murphy and A. N. Thompson. 2003. SGS Animal Production Theme: effect of grazing system on animal productivity and sustainability across southern Australia. *Australian Journal of Experimental Agriculture* 43: 977-991.

Graham, J. F., T. Prance, R. P. Thompson, D. Borg, P. Ball and P. Filsell. 2000. The effects of grazing management on perennial ryegrass (*Lolium perenne* L.) herbage mass and persistence in south-eastern Australia. *Australian Journal of Experimental Agriculture* 40: 207-224.

Grime, J. P. 1973. Competitive exclusion in herbaceous vegetation. *Nature* 242: 344-347.

Hill, M. J., P. J. Vickery, E. P. Furnival and G. E. Donald 1999. Pasture Land Cover in Eastern Australia from NOAA-AVHRR NDVI and Classified Landsat TM. *Remote Sensing of Environment* 67: 32-50.

Jackson, W. 2002. Natural systems agriculture: a truly radical alternative. *Agriculture, Ecosystems & Environment* 88: 111-117.

Kemp, D. R. and P. M. Dowling. 2000. Towards sustainable temperate perennial pastures. *Australian Journal of Experimental Agriculture* 40: 125-132.

Kemp, D. R., W. M. King, A. R. Gilmour, G. M. Lodge, S. R. Murphy, P. E. Quigley, P. Sanford and M. H. Andrew. 2003. SGS Biodiversity Theme: impact of plant biodiversity on the productivity and stability of grazing systems across southern Australia. *Australian Journal of Experimental Agriculture* 43: 961-975.

Kemp, D. R., D. L. Michalk and J. M. Virgona. 2000. Towards more sustainable pastures: lessons learnt. *Australian Journal of Experimental Agriculture* 40: 343-356.

Lancaster, M. L., M. G. Gardner, A. J. Fitch, T. H. Ansari and A. K. Smyth. 2012. A direct benefit of native saltbush revegetation for an endemic lizard (*Tiliqua rugosa*) in southern Australia. *Australian Journal of Zoology* 60: 192-198.

Le Houérou, H. N. 1992. The role of saltbushes (*Atriplex* spp.) in arid land rehabilitation in the Mediterranean Basin: a review. *Agroforestry Systems* 18: 107-148.

Lodge, G. M. and B. A. Orchard 2000. Effects of grazing management on <I>Sirosa phalaris</I> herbage mass and persistence in a predominantly summer rainfall environment. *Australian Journal of Experimental Agriculture* 40: 155-169.

Lodge, G. M. and R. D. B. Whalley. 1981. Establishment of Warm- and Cool-Season

Native Perennial Grasses on the North-West Slopes of New South Wales. I. Dormancy and Germination. *Australian Journal of Botany* 29: 111-119.

Lodge, G. M. and R. D. B. Whalley. 1983. Seasonal variations in the herbage mass, crude protein, and in-vitro digestibility of native perennial grasses on the North-West slopes of New South Wales. *Australian Rangeland Journal* 5(1): 20-27.

Lodge, G. M. and R. D. B. Whalley. 1989. 'Technical Bulletin 35: Native and natural pastures on the Northern Slopes and Tablelands of New South Wales.' (NSW Agriculture and Fisheries: Orange)

Lunt, I. D., D. J. Eldridge, J. W. Morgan and G. B. Witt. 2007. Turner Review No. 13 A framework to predict the effects of livestock grazing and grazing exclusion on conservation values in natural ecosystems in Australia. *Australian Journal of Botany* 55: 401-415.

Malcolm, B., K. F.Smith and J. L. Jacobs. 2014. Perennial pasture persistence: the economic perspective. *Crop and Pasture Science* 65: 713-720.

Mitchell, M. L., J. M. Virgona, J. L. Jacobs and D. R. Kemp. 2014. Population biology of *Microlaena stipoides* in a south-eastern Australian pasture. *Crop and Pasture Science* 65: 767-779.

Ni, J. 2004. Estimating net primary productivity of grasslands from field biomass measurements in temperate northern China. *Plant Ecology* 174: 217-234.

Nie, Z. N. and R. P. Zollinger. 2011. Impact of deferred grazing and fertilizer on plant population density, ground cover and soil moisture of native pastures in steep hill country of southern Australia. *Grass and Forage Science* 67: 231-242.

Owensby, C. E. and L. M. Auen. 2013. Comparison of Season-Long Grazing Applied Annually and a 2-Year Rotation of Intensive Early Stocking Plus Late-Season Grazing and Season-Long Grazing. *Rangeland Ecology & Management* 66: 700-705.

Owensby, C. E., L. M. Auen, H. F. Berns and K. C. Dhuyvetter. 2008. Grazing Systems for Yearling Cattle on Tallgrass Prairie. *Rangeland Ecology & Management* 61: 204-210.

Reseigh, J., C. Nadolny and N. Reid. 2003. Effects of recent changes in grazing and fertiliser management on the species richness of native ground-storey vegetation, Northern Tablelands, New South Wales. In 'Rural Land Use Change - YES! - But will biodiversity be okay? Attwood, Australia', 1-9. (Eds J Crosthwaite, Q Farmer-Bowers, C Hollier) (Department of Sustainability and Environment: Attwood, Australia)

Simpson, P. and C. Langford. 1996. Whole-farm management of grazing systems based on native and introduced species. *New Zealand Journal of Agricultural Research* 39: 601-609.

Tillman, D. 1982. 'Resource competition and community structure.' (Princeton University Press: Princeton)

Van Tassel, D. and L. DeHaan. 2013. Wild Plants to the Rescue. *American Scientist* 101: 218-225.

Vere, D. T., R. E. Jones and M. H. Campbell. 2001. The economics of temperate pasture systems on the central and southern Tablelands of New South Wales. *The Rangeland Journal* 23: 159-172.

Virgona, J. 2006. Expanding EverGraze into Native pastures: Directions Paper. EverGraze, Future Farm Industries CRC, Perth. Available at http://www.evergraze.com.au/library-content/native-pastures-directions-paper/ [Accessed 8th September 2014].

Virgona, J, and M. Mitchell. 2011. Grazing to manipulate composition in native pastures - improving red grass content in native pastures. In '7th National Native Grasslands Conference: Managing Native Grasslands for Soil and Animal Health. Holbrook, NSW'. pp. 23-28. (Stipa Native Grasses Association: Holbrook, NSW). Available at http://www.stipa.com.au/Events/Conferences2011.html

Virgona, J., M. Mitchell and A. Ridley. 2003. Native pastures - research and development directions with respect to the mitigation of dryland salinity. In 'The 2002 Australian Academy of Science Fenner Conference on the Environment: Agriculture for the Australian Environment. Canberra', 2003. (The Johnstone Centre, Charles Sturt University, Albury. Available at

http://www.csu.edu.au/special/fenner/papers/ref/17%20Virgona%20Jim.pdf

Virgona, J. M., A. L. Avery, J, F. Graham and B. A. Orchard. 2000. Effects of grazing management on phalaris herbage mass and persistence in summer-dry environments. *Australian Journal of Experimental Agriculture* 40: 171-184.

Wolfe, E. 2009. Forage Resource Profile—Australia. FAO, Rome. Available at http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Australia/australia.htm.

Xiangming, X., J. Shu, W. Yifeng, D. S. Ojima and C. D. Bonham. 1996. Temporal variation in aboveground biomass ofLeymus chinense steppe from species to community levels in the Xilin River Basin, Inner Mongolia, China. *Vegetatio* 123: 1-12.